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Wave Model Validation for the Northern Gulf of Mexico Littoral Initiative (NGLI) Project

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13. ABSTRACT (*Maximum 200 words*)

This report documents the wave measurement and modeling efforts supporting the Northern Gulf of Mexico Littoral Initiative (NGLI). Data from three NDBC buoys acquired during September 2000 are used to validate COAMPS, WAM, and two shallow water wave models – STWAVE and SWAN. Statistical errors of model estimates of significant wave height, mean wave period, mean wave direction, wind speed, and wind direction are computed. Both COAMPS and WAM produce accurate input conditions for driving the shallow water models. SWAN performance is found to be better than that of STWAVE. STWAVE's poorer performance is caused mainly by its limitation in specifying imput wind and wave conditions. Various SWAN modeling parameters are evaluated. Based on the evaluation and validation, an operational wave model using SWAN for the NGLI region has been developed.

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WAVE MODEL VALIDATION FOR THE NORTHERN GULF OF MEXICO LITTORAL INITIATIVE (NGLI) PROJECT

1. INTRODUCTION

The Northern Gulf of Mexico Littoral Initiative (NGLI) is a multi-agency effort to develop an oceanographic simulation and monitoring capability for the Mississippi Sound and its adjoining waters encompassing the rivers, bays, and coastal regions of eastern Louisiana, Mississippi, and Alabama. NGLI is supported by federal agencies, including the Naval Oceanographic Office (NAVOCEANO) under the Commander, Naval Meteorological and Oceanographic Command (CNMOC) and the Environmental Protection Agency's Gulf of Mexico Program Office (EPA-GMPO). One of the main objectives is to develop a modeling system consisting of a three-dimensional circulation model, a sand-silt sediment transport model, and a wave model. The prediction system will use mapping technology, allowing users to generate curvilinear and orthogonal grids for a suite of models. Automated assimilation methods will be integrated into the system to provide means of handling open boundary conditions for coupling with larger scale models, data for initializing the model, and surface forcing of different types. Turbidity, current, temperature, salinity, and directional wave measurements are collected for model validation.

To support NGLI efforts, it is necessary to evaluate the wave models suitable for shallow water simulation and to develop an operational forecasting wave model. This report documents a wave data collection effort conducted during September 1 through 14, 2000 and evaluates the associated post-collection wave hindcasting using the following wave models:

- WAM (Wave Model)
- SWAN (Simulation of Waves in Nearshore Areas Model)
- STWAVE (Steady State Wave Model)

Additionally, wind speed and direction estimates from the COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) atmospheric model, used to drive all wave models, are compared to corresponding National Data Buoy Center (NDBC) wind measurements.

Validating wind and wave data were acquired from two operational NDBC buoys and an experimental NDBC buoy deployed for NGLI. Data were also collected from a Sea-Bird wave recorder (SBE26) and a small, directional wave measurement buoy from Neptune Sciences, Inc. These data are evaluated against corresponding NDBC data to examine the effectiveness of these instruments for relatively low cost data collection during later stages of the NGLI.

This report focuses on the statistical errors of model estimates of significant wave height H_{mo}, average wave period T_{avg}, average wave direction θ_{avg}, wind speed U, and wind direction θ_U valid at the location of three NDBC directional wave buoys. We show that the COAMPS model provides highly accurate wind

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estimates and WAM provides good wave boundary conditions. The SWAN model provides relatively higher wave hindcasting skill than that from the STWAVE model.

2. OVERVIEW OF MODELS

This section gives an overview of the models used in the validation study. The cited references give detailed descriptions of the models.

2.1 COAMPS

COAMPS represents an analysis-nowcast and short-term forecast tool applicable for any given region of the earth. COAMPS includes an atmospheric data assimilation system comprised of data quality control, analysis, initialization, and nonhydrostatic atmospheric model components and a choice of two hydrostatic ocean models (Hodur and Doyle 1998). Observations from aircraft, ships, and satellites are blended with the first-guess fields to generate the current analysis. The atmospheric model uses nested grids to achieve high-resolution for a given area and contains parameterizations for subgrid scale mixing, cumulus parameterization, radiation, and explicit moist physics. On the mesoscale, it has frequently provided better surface wind prediction than the other wind models.

In this study, the whole Gulf of Mexico, and therefore the entire NGLI region, is covered within the larger Central American grid, which has a resolution of 0.2 degree or about 27 km. It is run twice daily, providing hourly forecasts of up to 48 hours.

2.2 WAM

The WAM wave model is a spectral wave prediction model developed by the WAMDI Group (1988). It is a third-generation wind wave model that introduces no ad hoc assumptions on the spectral shape. It is the primary wave forecast model of NAVOCEANO. WAM produces directional spectra of spectral energy density in 25 frequency bins ranging from 0.0433 to 0.328 Hz and in 24 15-degree-wide directional sectors from which significant wave height, average wave period and average wave direction can be computed. It is noted that WAM rarely runs with a resolution higher than 5 minutes or 8 km due to its explicit numerical scheme. Higher resolution such as 1 km as required by the rapid changing bathymetry in shallow water will require excessive computation time.

For this study, a 5-minute resolution WAM is nested with the quarter-degree resolution Gulf of Mexico run, which is nested with global WAM. Both regional WAM models use COAMPS wind. Directional spectra for selected boundary points from the WAM are saved. The WAM provides directional waves spectra at each point for forecast up to 48 hours at three-hour interval. The spectra are used as inputs for the SWAN and STWAVE shallow-water wave models.

2.3 STWAVE

STWAVE is a steady state spectral model based on the wave action balance equation (Smith et al.1999). In addition to wind generation, it simulates shallow water physics such as depth-induced wave refraction and shoaling, and wave diffraction. It is designed for a small-region simulation where the steady state assumption is valid. STWAVE has limited options in defining wind and wave input conditions.

2.4 SWAN

Similar to WAM and STWAVE, SWAN is a third-generation wave model (Booij et al. 1999). It computes wind-generated waves in coastal regions and inland waters. Version 40.11 is used in this study. SWAN accounts for the following physics:

- wave propagation in time and space, shoaling, and refraction due to current and depth
- wave generation by windnonlinear three- and four-wave interactions
- whitecapping, bottom friction, and depth-induced breaking
- wave-induced setup

3. INSTRUMENTATION

Figure 1 illustrates the NGLI area of the study, including the location of wave sensors and model domain. The area is rotated to minimize the computation time. In addition, the southern boundary is selected to be parallel to the bathymetry contours. This is necessary for some STWAVE runs (discussed in Section 7.3) using wave data from buoy 42040 as input at the boundary.

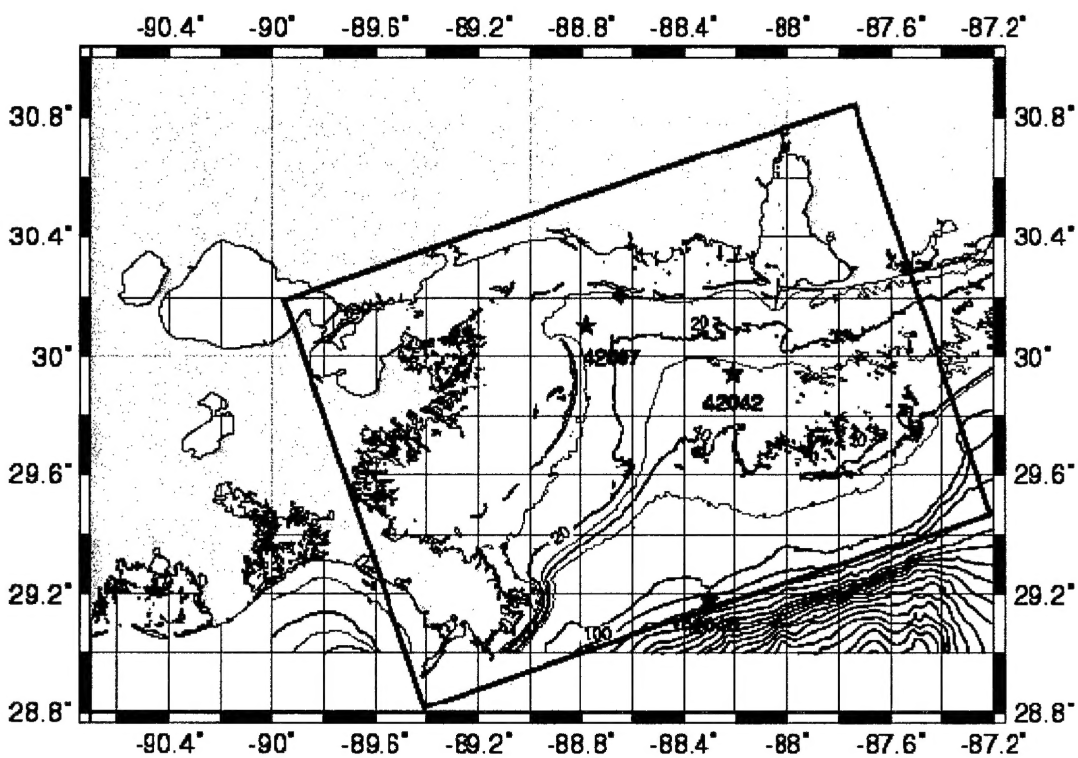

Fig. 1 — NGLI depths in meters, locations of NDBC buoys (stars), SeaBird pressure gauge (square), and Neptune buoy (triangle)

This section briefly describes the instruments used for measuring ocean waves during the course of the data collection period.

3.1 NDBC Wave Buoys

The three NDBC directional wave buoys used for model validation are each 3-meter discus buoys with an onboard Datawell Hippy 40 that measures buoy heave acceleration, pitch angle, and roll angle. Wave measurements provided by NDBC buoys, including directional wave measurements, enjoy a reputation for high quality. Data from three NDBC stations used in this report are given in Table 1.

Table 1 — Locations and Depths of NDBC Stations

Station ID	Latitude (degrees N)	Longitude (degrees W)	Depth (m)
42007	30.1000	88.7800	13.4
42042	29.2000	88.2500	35
42040	29.8917	88.3208	238

3.2 SeaBird Wave and Tide Recorder

As shown in Fig. 1, the SeaBird (SBE26) was deployed in 4-m-deep water off the south coast of Horn Island at 30.23 N, 88.65 degrees W. The sensor was configured to record a tide measurement every other hour followed by a wave burst data acquisition sequence that consisted of 2048 water elevation measurements at a rate of 2 Hz for a period of about 17 min.

3.3 Trident Wave Buoy

The Trident wave buoy is a newly developed and relatively low-cost instrument that reports several directional and nondirectional wave parameters computed onboard the buoy. The sensors consist of a triaxial magnetometer and an along-mast accelerometer. It samples for 17 minutes at a rate of 4 Hz once each hour. Owing to extremely small wave heights measured during deployments in the Mississippi Sound, only deployments 1 and 2 are presented in this report. The small wave condition is due to island sheltering of waves and lack of strong wind during the short measurement period. Table 2 summarizes the Trident deployments during the course of the data collection period. The buoy was deployed around 7 m depth.

Table 2 — Summary of Trident Wave Buoy Deployments

Deployment	Cases	Latitude (degrees N)	Longitude (degrees W)	Starting Day and Hour (CST) Sept. 2000	Ending Day and Hour (CST) Sept. 2000
1	10	30.2225	87.3517	1 1300	1 2200
2	46	30.2227	87.3496	12 1400	14 1100

4. DATA REDUCTION

Wave parameters compared in this report are the significant wave height, the average wave period, and the average wave direction. Unless otherwise stated, height is expressed in meters, periods are expressed in seconds, and wave direction is expressed as the direction from which waves are coming in degrees clockwise from true North.

4.1 NDBC Buoys

The NDBC data were downloaded directly from the NDBC web site at *www.ndbc.noaa.gov*. Mean wind speed and direction are obtained from 8.5-minute records sampled at a rate of 1 Hz. Wave spectra are computed onboard the buoy each hour from a combination of 40-, 20- and 10-minute pitch, roll, and heave acceleration records. Near-real-time measurements are posted on the web site within 24 hours of satellite reception of the data; however, quality checked data are posted to the web site within one to two months of data acquisition. The data in this report are quality-checked data, which are listed with greater precision than the near-real-time data.

4.2 SeaBird Pressure Gauge

The data were downloaded from the sensor after it was retrieved from the water. Spikes in the time series data caused the manufacturer-provided software to give erroneous wave parameters. Thus, it was necessary to manually remove outliers in the time series and then reanalyze the clean time series using standard fast Fourier transform techniques. After demeaning and detrending the remaining acceptable tide elevation measurements, the wave pressure spectrum was computed from each 17.0667-minute record (2048 points at a sampling rate of 2 Hz). The wave spectrum was then derived by applying the depth attenuation factor to each component of the pressure spectrum except those representing a high wave frequency. A total of 131 wave spectra covering the time period from 1300 UTC (coordinated universal time, formerly called GMT or Greenwich Mean Time) September 1 to 1400 UTC September 13, 2000, generally every 2 hours over a 13-day period, were computed. Wave parameters of wave height and average wave period were then derived from each of these spectra using standard techniques.[1]

4.3 Trident Wave Buoy

The data were downloaded from the buoy payload using the software provided by the manufacturer. The software provides water temperature, significant wave height, first peak wave period, peak wave direction, average wave direction, primary direction of swell waves, and primary direction of wind waves. There is no need to post-process the data after they are downloaded from the buoy payload.

5. WIND AND WAVE CONDITIONS

Figures 2 and 3 illustrate the wind and wave conditions at buoys 42042 and 42040. During the study period, winds ranged from near calm to a strong breeze within a general regime of moderate easterly flow. From the wave height plot, there are two major wave events (all wave heights referred to in this report are significant wave height). One event starts on September 5 with easterly wind, and waves are locally generated waves. The other starts on September 16 and is a combination of the arrival of 11-second swell from tropical storm Gordon off south Florida and locally generated waves. Tables 4 and 5 summarize the wind and wave conditions at buoys 42040 and 42042.

[1] Later, the spikes in the downloaded data were found to be caused by the interference of background window software at the communication port. During downloading, the user needs to boot the computer in DOS to avoid the interrupt.

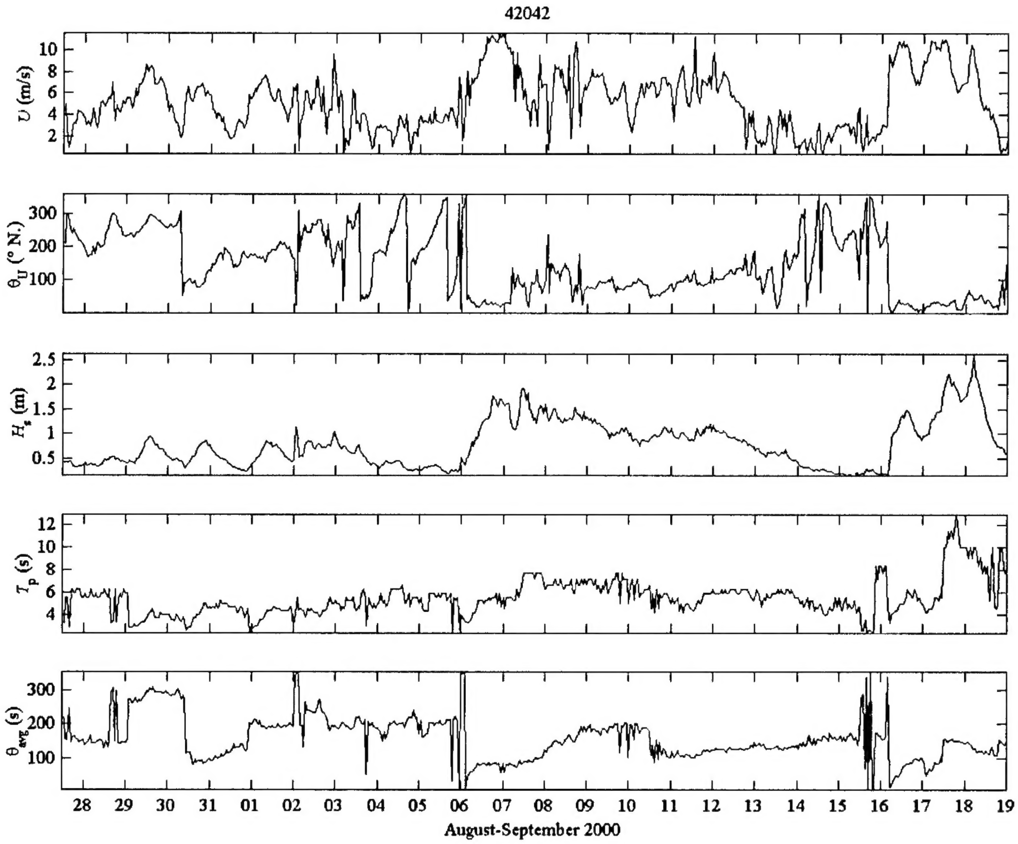

Fig. 2 — Time series of wind and wave conditions at station 42042

Table 3 — Statistics of Wind and Wave Conditions at NDBC Station 42042 from 1200 UTC August 28 to 0000 UTC September 19, 2000

Parameter	Minimum	Mean	Maximum
U (m/s)	0.4	5.0	11.5
θ_U (° N.)	1	87.7	359
H_s (m)	0.16	0.75	2.62
T_p	2.4	5.5	12.9
θ_{avg} (° N.)	6	156.4	353

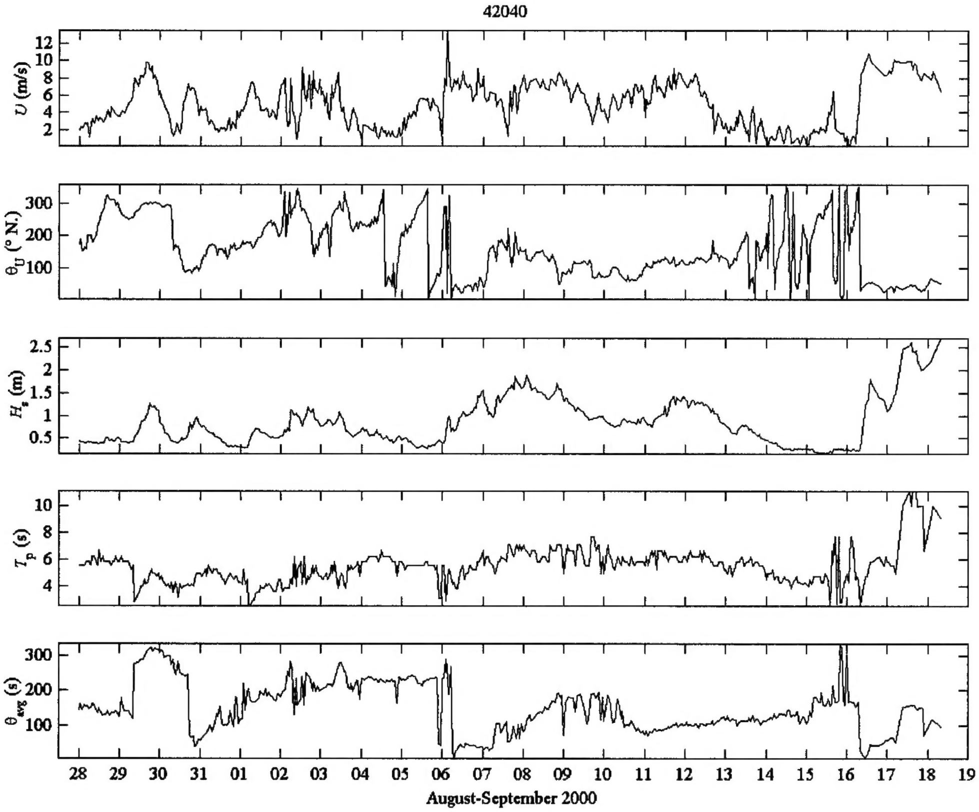

Fig. 3 — Time series of wind and wave conditions at station 42040

Table 4 — Statistics of Wind and Wave Conditions at NDBC Station 42040 from 1200 UTC August 28 to 0000 UTC September 19, 2000

Parameter	Minimum	Mean	Maximum
U (m/s)	0.1	4.8	13.5
θ_U (°N)	2	101.2	360
H_s (m)	0.16	0.82	2.70
T_p	2.6	5.5	11.11
θ_{avg} (°N)	6	153.1	333

6. SENSOR COMPARISON

This section compares wave parameters obtained from the Trident wave buoy, the SeaBird pressure gauge, and NDBC measurements.

6.1 Trident and SBE26

As illustrated in Fig. 1, Trident and the SBE26 are both deployed south of Horn Island. Trident is deployed at 7 m whereas SBE26 is at 4 m. Because of the slight difference in depth, we see some differences in wave heights. Error statistics of the two deployments are summarized in Table 5 and time series and scatter plots are given in Figs. 4 through 7. The wave height of SBE26 is slightly higher, as expected. The average wave period from both sensors is expected to be the same, but the period from the Trident is slightly higher than that from the pressure gauge.

Table 5 — Error Statistics of Wave Height (Meters) and Average Wave Period (Seconds) Derived from Trident Wave Buoy Minus Corresponding Parameters from Collocated SBE26

Deployment 1					
N	***R***	***RMS***	***m***	***b***	***parameter***
5	0.78	0.27	0.72	-0.07	H_s
5	0.95	0.33	0.69	1.47	T_{avg}
Deployment 2					
N	***R***	***RMS***	***m***	***b***	***parameter***
13	0.93	0.2	0.62	0.029	H_s
13	0.64	0.46	0.47	2.69	T_{avg}

N is the number of comparisons; *R* is the linear correlation coefficient between the model estimates and measurements; *RMS* is the root-mean-squares error; *m* is the slope of the linear regression curve through the set of model-measurement pairs; and *b* is the *y*-intercept of the linear regression curve through the set of model-measurement pairs.

6.2 Trident and NDBC Station 42007

There were only 25 hours of collocated measurements from the Trident and NDBC Station 42007. As seen from the summary of error statistics in Table 6 and the time series plots of wave height, period, and direction in Fig. 8, the performance of the Trident compared to the NDBC buoy is reasonable for wave height and period. The scatter plots for wave height, average period, and angle are shown in Fig. 9. It should be noted that Trident shows a slightly longer wave period than those of both station 42007 and the pressure gauge. The average wave angle from the buoy appears to have a bias. But the deployment duration is too short to draw any conclusion. Longer duration measurement under a variety of wave angle conditions is needed for detailed investigation of its angular performance. Figure 10 shows the scatter plots between the pressure gauge and station 42007. They are not collocated, so we expect to see some differences in wave height. For wave period, the agreement is quite good except that the pressure gauge has a few outliers at short wave periods.

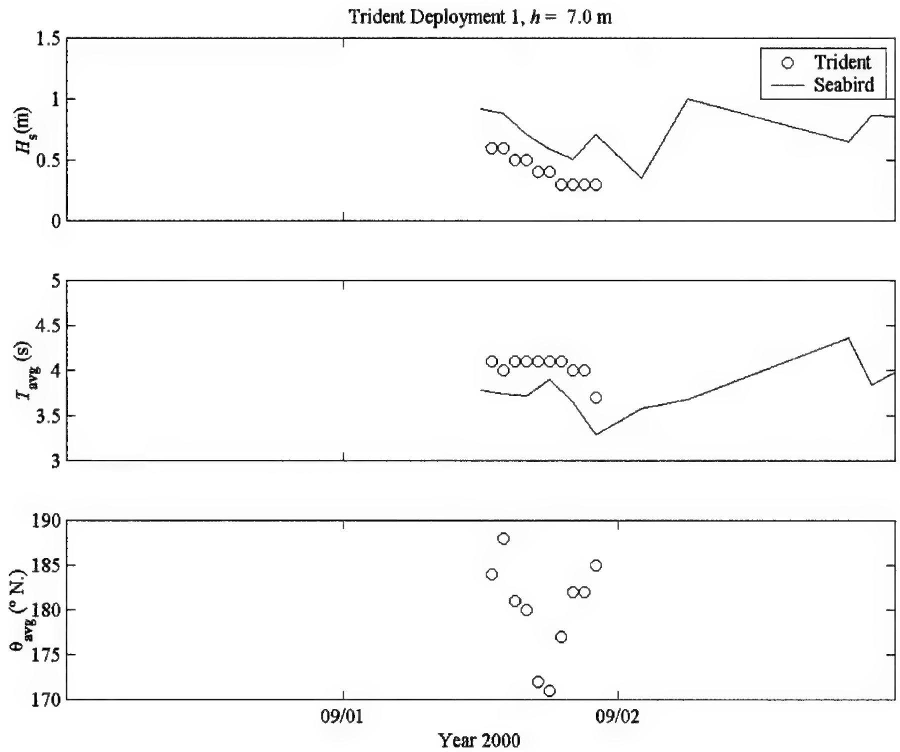

Fig. 4 — Time series of wave parameters from Trident wave buoy and SeaBird SBE26 during Deployment 1

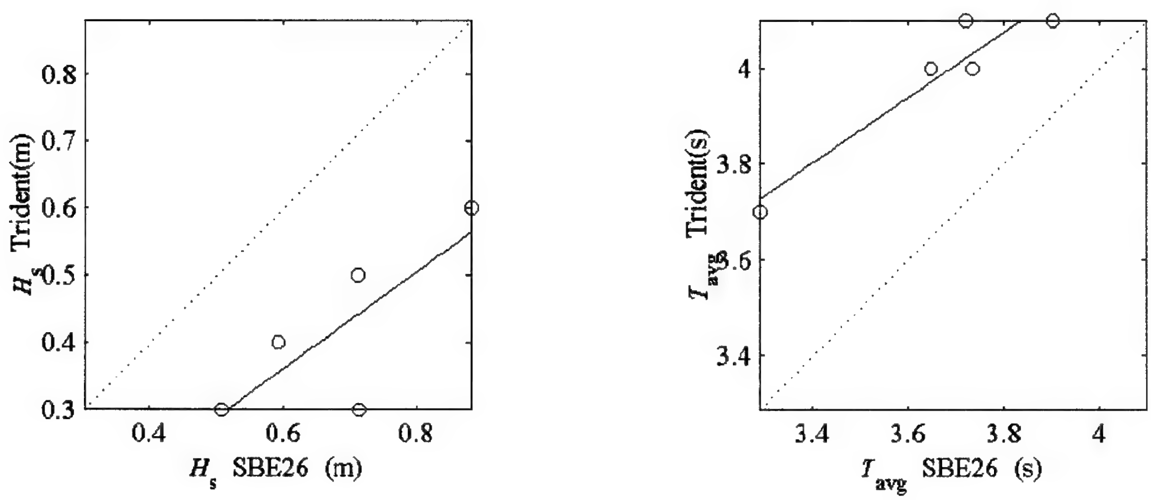

Fig. 5 — Scatter plots of wave parameters from Trident wave buoy and SeaBird SBE26 during Deployment 1

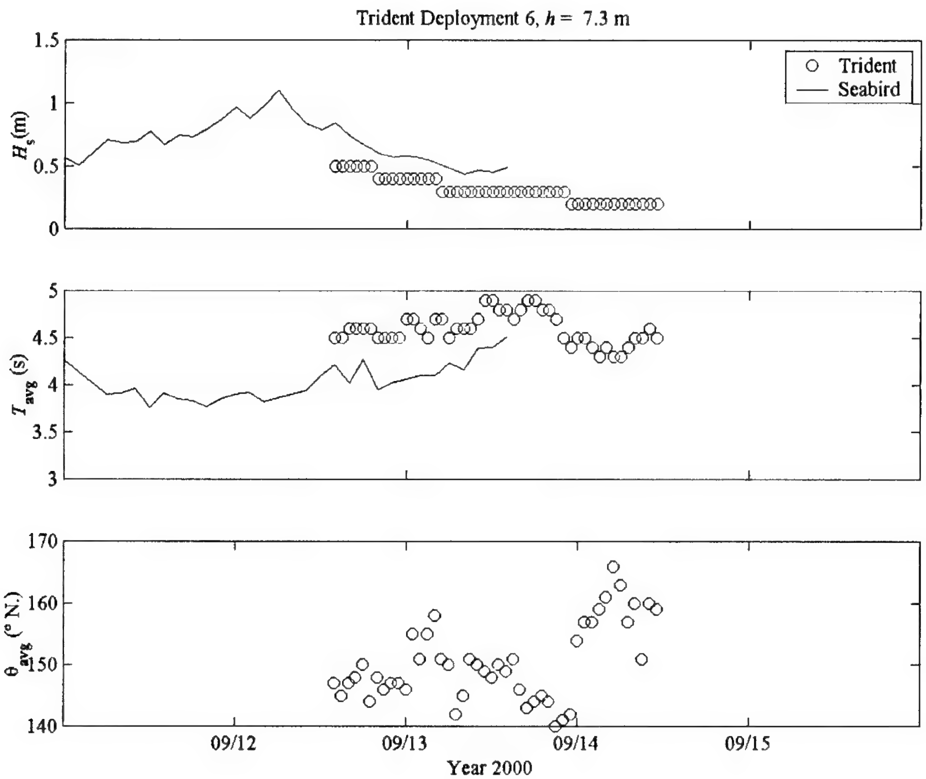

Fig. 6 — Time series of wave parameters from Trident wave buoy and SeaBird SBE26 during Deployment 2

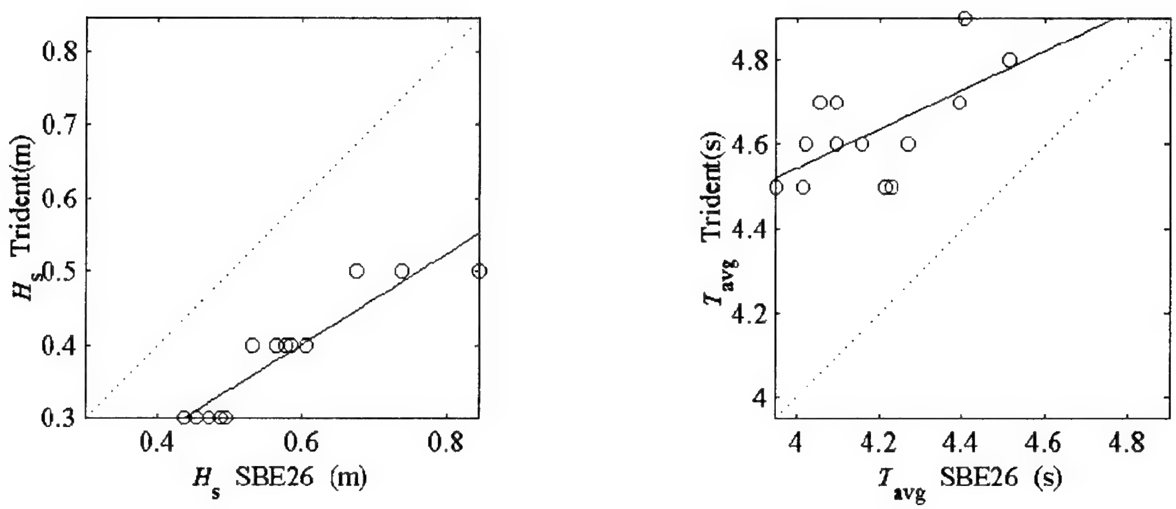

Fig. 7 — Scatter plots of wave parameters from Trident wave buoy and SeaBird SBE26 during Deployment 2

Table 6 — Error Statistics of Wave Height (Meters), Average Wave Period (Seconds), and Average Wave Direction (θ_{Avg}) from Trident Wave Buoy Minus Corresponding Parameters of NDBC Station 42007

N	*R*	*RMS*	*m*	*b*	parameter
25	0.810	0.11	0.92	-0.011	H_s
25	0.847	0.27	0.7	1.54	T_{avg}
25	0.703	13.8	0.74	41.3	θ_{avg}

N is the number of comparisons; *R* is the linear correlation coefficient between the model estimates and measurements; *RMS* is the root-mean-squares error; *m* is the slope of the linear regression curve through the set of model-measurement pairs; and *b* is the *y*-intercept of the linear regression curve through the set of model-measurement pairs.

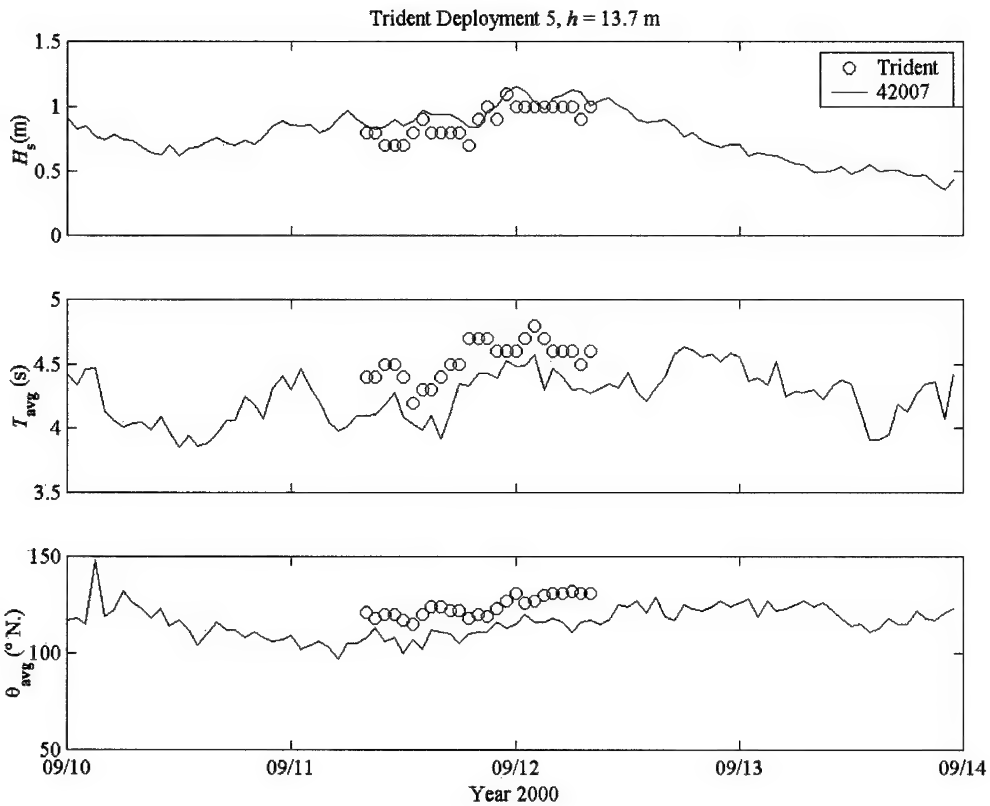

Fig. 8 — Time series of wave height, period, and direction from NDBC Station 42007 and the Trident wave buoy

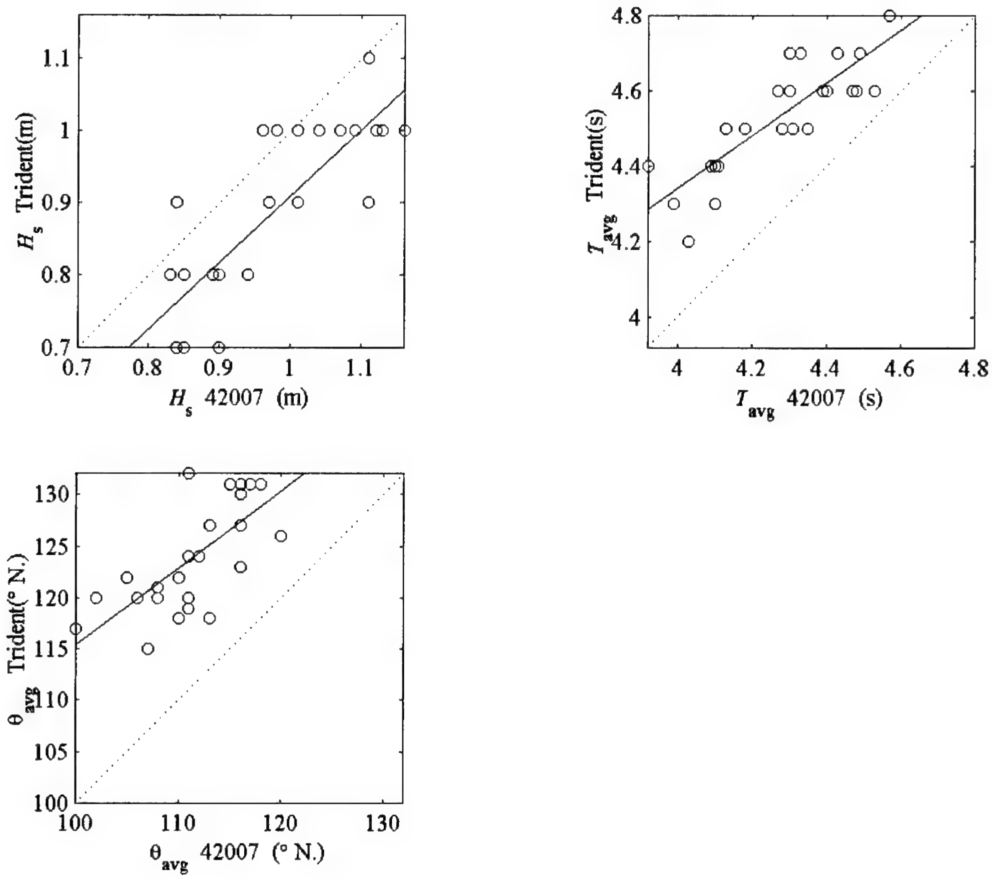

Fig. 9 — Scatter plots of wave height, period, and direction from buoy 42007 and the Trident wave buoy

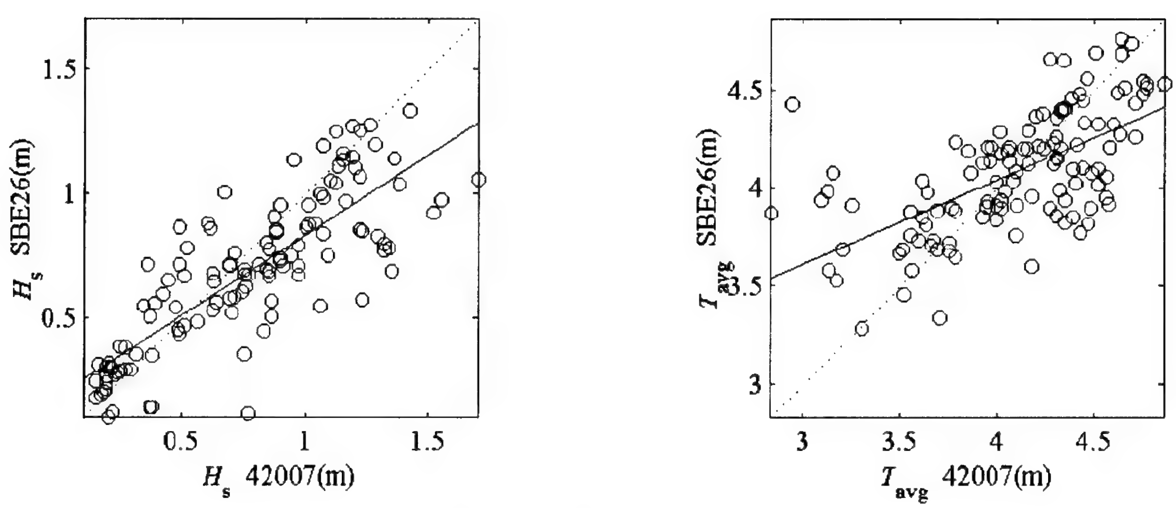

Fig. 10 — Scatter plot of SBE26 and 42007 wave heights and average wave periods

7. MODEL VALIDATIONS

This section gives the results of the comparison between NDBC buoy measurements of wind speed, wind direction, significant wave height, average wave period, and average wave direction and corresponding model estimates. Wind estimates are from the COAMPS model only. Wave estimates are from the WAM, SWAN, and STWAVE models. SWAN computations are conducted in this study on a regular grid in Cartesian coordinates. Three-hourly WAM spectra representing wave conditions at nine geographic locations along the southern, western, and eastern edges of the bathymetric grid are used as the boundary condition. The results are from a run using a grid spacing of 1 km by 1 km. Previous study has indicated that increasingly finer grid resolution in this region does not produce much difference in the results (Hsu et al. 2000).

Both error statistics between the various model-estimates of wind or wave parameters and each of the three NDBC stations and corresponding time series plots and scatter diagrams are presented here.

7.1 COAMPS

Figure 11 compares COAMPS and three NDBC buoy wind measurements. In general, their agreement is quite good. The scatter plots of wind speed and average direction are presented in Fig. 12. As shown by the error statistics in Table 7, COAMPS wind speeds are of relatively high quality, with estimated wind speeds showing an average RMS error of 2 m/s. The RMS error of wind direction is 49.4 degree. A much smaller value can be achieved if the data include only wind speeds exceeding 0.5 m/s. Buoy winds at such low wind speeds show many fluctuations.

Table 7 — Error Statistics of COAMPS Model Minus NDBC Buoy Station Wind Measurements (Wind Speed in Meters/Second, Wind Directions in Degrees Clockwise from North)

42007					
N	***R***	***RMS***	***m***	***b***	***model***
167	0.77	1.95	0.852	0.45	COAMPS U
167	0.89	51.8	1.07	-7.1	COAMPS θ_U
42042					
N	***R***	***RMS***	***m***	***b***	***model***
166	0.76	2.0	0.86	0.97	COAMPS U
166	0.92	46.3	1.09	-1.9	COAMPS θ_U
42040					
N	***R***	***RMS***	***m***	***b***	***model***
153	0.73	2.1	0.75	1.42	COAMPS U
153	0.88	50.0	1.01	-6.6	COAMPS θ_U

N is the number of comparisons; *R* is the linear correlation coefficient between the model estimates and measurements; *RMS* is the root-mean-squares error; *m* is the slope of the linear regression curve through the set of model-measurement pairs; and *b* is the *y*-intercept of the linear regression curve through the set of model-measurement pairs.

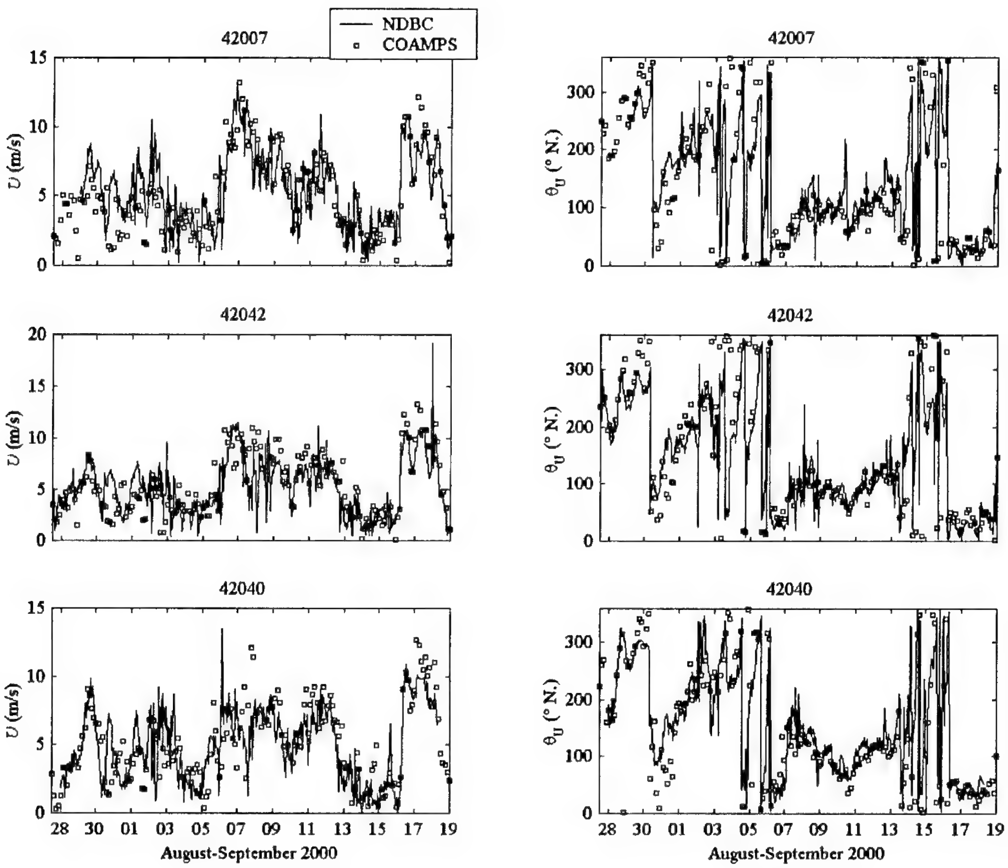

Fig. 11 — Time series of COAMPS wind estimates and NDBC wind measurements. Circles represent buoy data.

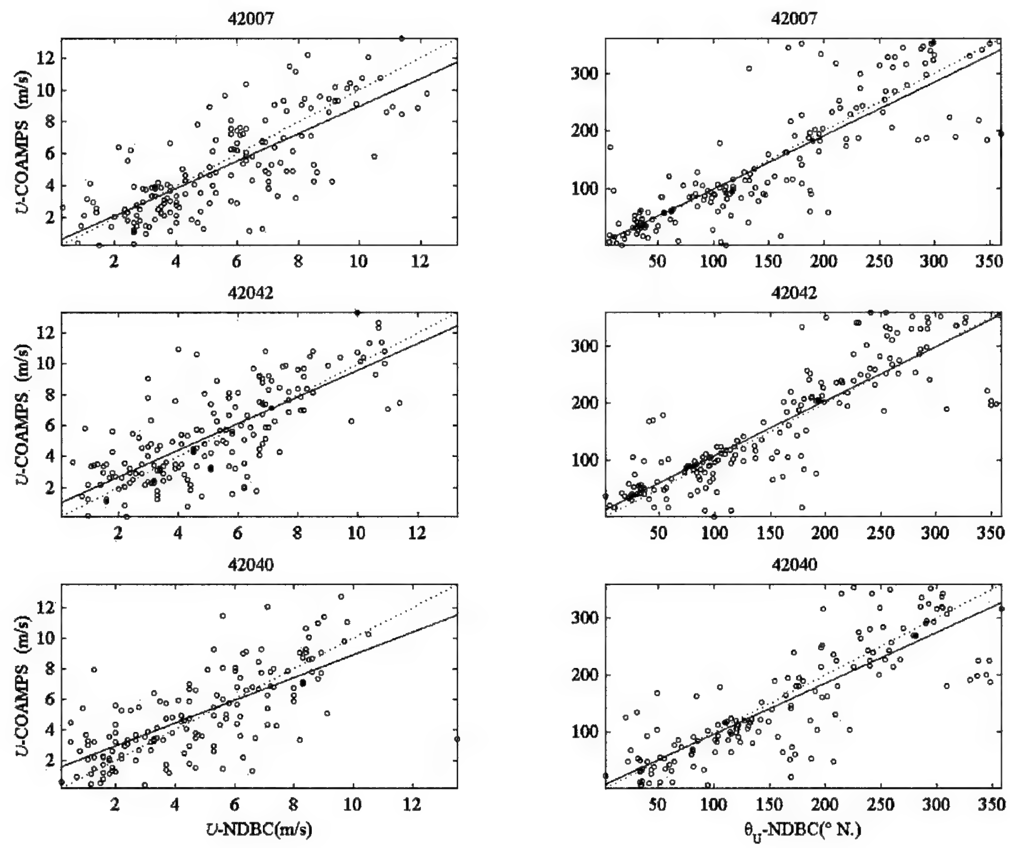

Fig. 12 — Scatter diagrams of COAMPS wind estimates vs NDBC measurements

7.2 WAM at Deep Water Boundary

The model domain is chosen such that buoy 42040 falls on its deepwater boundary. Figure 13 shows the comparison between WAM and the buoy and Table 8 presents the error statistics. WAM produces excellent wave height agreement. The average period agreement is very good except towards the end where a swell event occurred. Section 8.2 presents further discussion of WAM under the swell event.

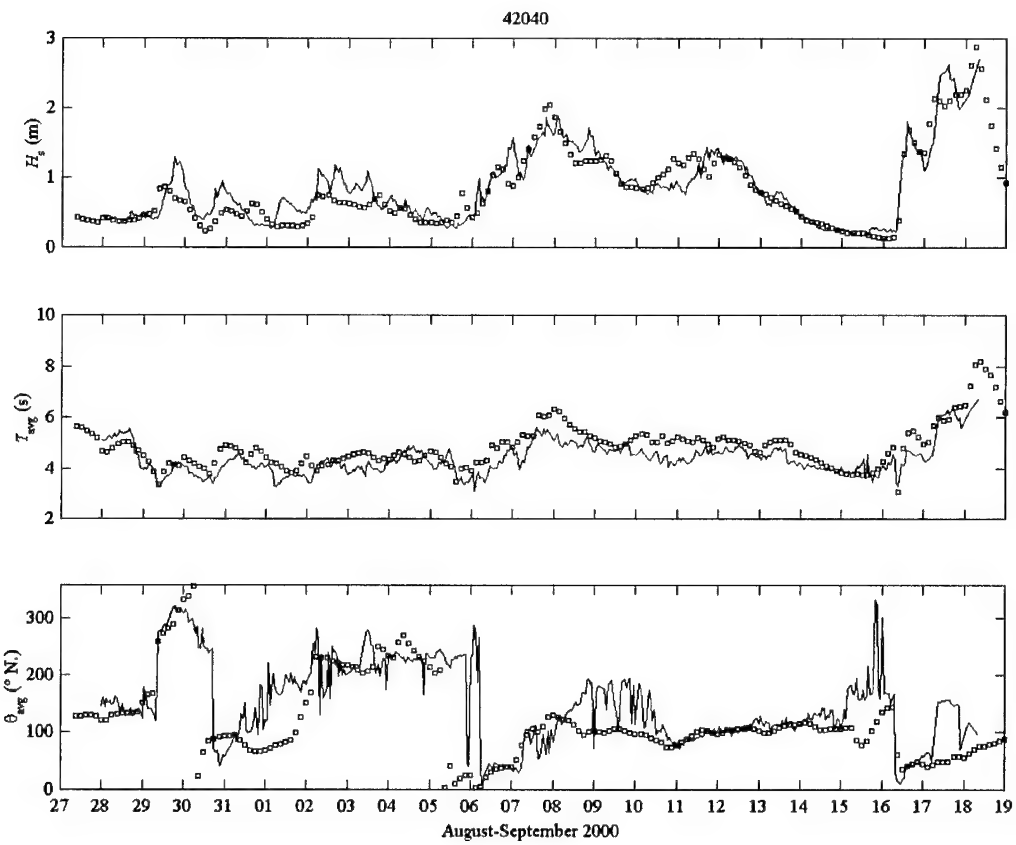

Fig. 13 — Time series of wave parameters estimates from the WAM at the boundary of the SWAN model grid at the location of buoy 42040 and the corresponding wave parameters from the buoy (solid line)

Table 8 — Error Statistics of WAM Model at NDBC 42040

N	***R***	***RMS***	***m***	***b***	**model**
153	0.91	0.21	0.96	-0.013	WAM H_s
153	0.81	0.48	0.88	0.85	WAM T_{avg}
153	0.63	24.1	0.63	24.0	WAM θ_{avg}

N is the number of comparisons; *R* is the linear correlation coefficient between the model estimates and measurements; *RMS* is the root-mean-squares error; *m* is the slope of the linear regression curve through the set of model-measurement pairs; and *b* is the *y*-intercept of the linear regression curve through the set of model-measurement pairs.

7.3 WAM, SWAN, and STWAVE at Shallower Depths

The comparison of time series model estimates and buoy 42042 data and their scatter plots are shown in Figs. 14 and 15. Their comparisons with buoy 42007 are shown in Figs. 16 and 17. The error statistics is presented in Tables 9 and10. To evaluate the impact of wave input conditions, two STWAVE runs are presented here, with one using WAM ($STWAVE_W$) and one using buoy 42040 as input ($STWAVE_N$). The best modeled wave parameter from among height, period and direction and from among the three models—WAM, SWAN, and STWAVE—is wave height, which consistently has the highest correlation between estimates and measurements. WAM performance at 42042 (35 m depth) is better than at 42007 (13.4 m depth). This is expected because WAM is running at 8 km resolution, therefore it cannot account for effects of the rapid depth changes at shallower water. The average RMS error in wave height for SWAN is 0.3 m. In general, STWAVE performs less skillfully than SWAN. Using measured buoy directional data as input, $STWAVE_N$ does not give better performance than $STWAVE_W$. STWAVE's performance is affected by being a half-plane wave model in which only waves heading to the shoreline are computed. In addition, no side boundary condition can be specified.

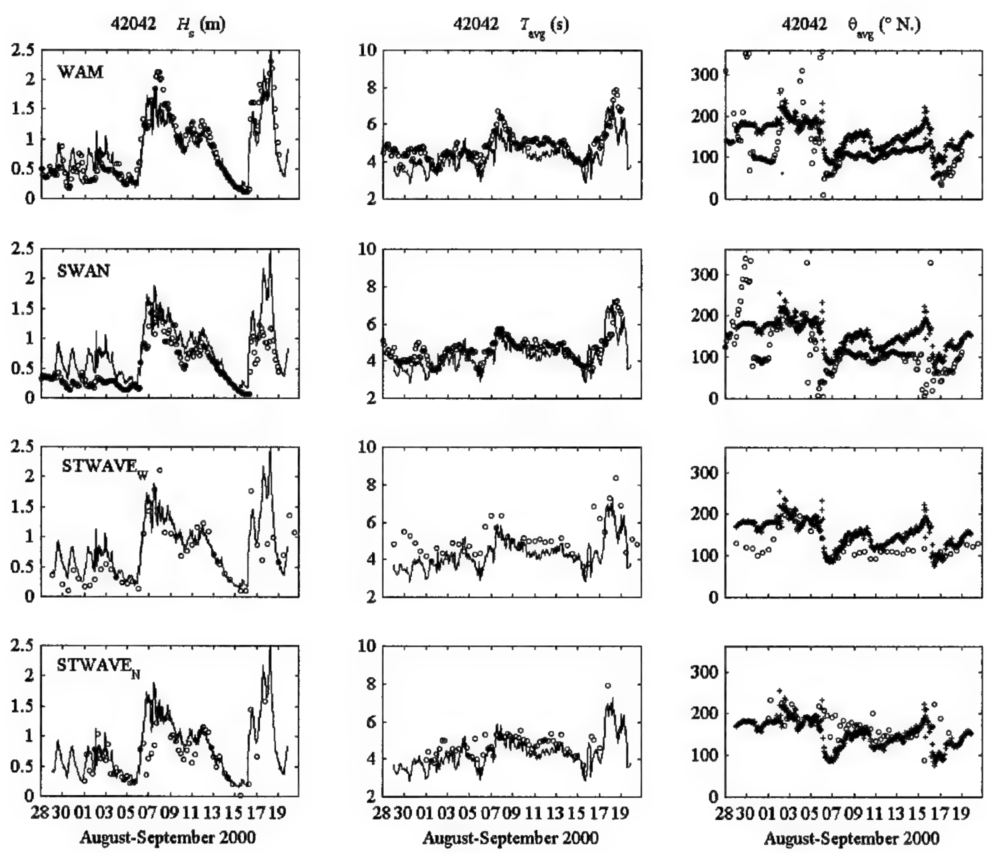

Fig. 14 — Times series of wave model estimates and NDBC measurements for wave parameters (solid line) at the buoy locations indicated

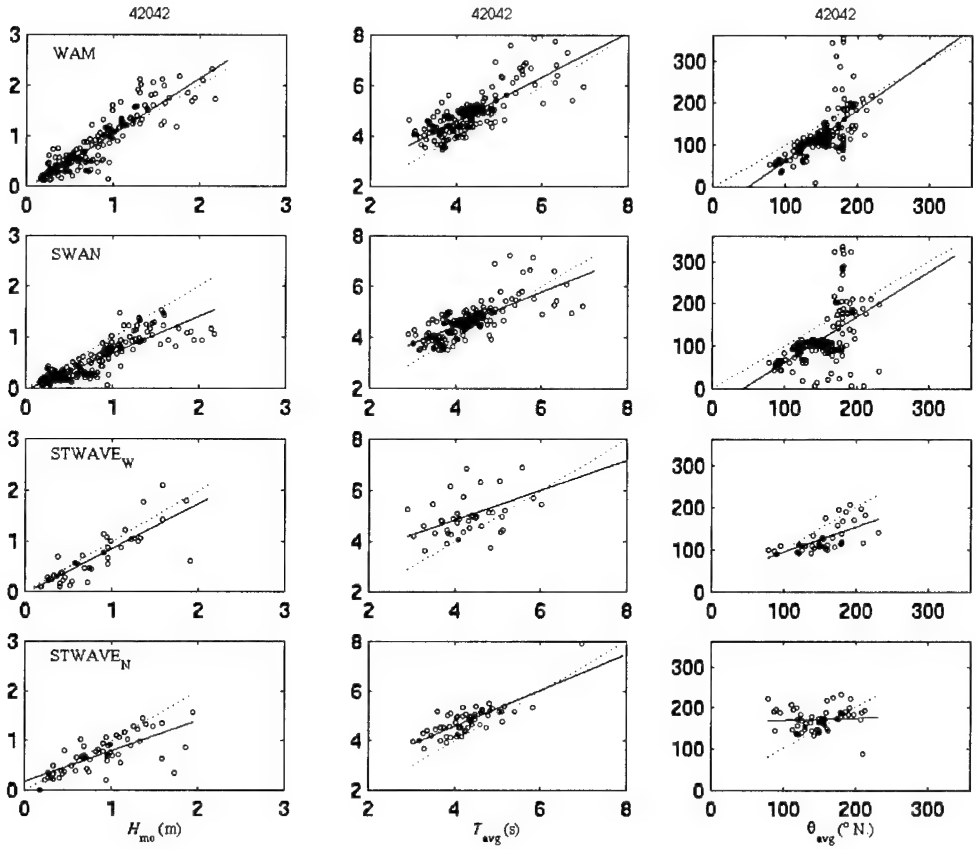

Fig. 15 — Scatter diagram of wave model estimates vs corresponding NDBC measurements for wave parameters at the buoy locations indicated. The solid line is the best-fitted linear regression line through the points. The dotted line has a slope of unity and a y-intercept of zero.

Table 9 — Error Statistics of WAM, SWAN, and STWAVE Model Runs Minus NDBC Station 42042 for the Wave Parameters Wave Height, Average Wave Period, and Average Wave Direction Given in Figs. 14 and 15

42042 wave height (m)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	173	166	41	56
R	0.90	0.86	0.83	0.72
RMS	0.26	0.30	0.31	0.34
M	1.10	0.71	0.90	0.61
B	-0.04	0.03	-0.04	0.18

42042 average wave period (s)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	173	166	41	63
R	0.79	0.74	0.48	0.39
RMS	0.75	0.61	1.12	0.65
M	0.85	0.68	0.59	0.73
B	1.18	1.69	2.50	1.65

42042 average wave direction (deg N)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	173	165	41	63
R	0.6	0.58	0.65	-0.13
RMS	34.4	34.8	30.0	26.8
m	1.2	1.1	0.59	0.1
b	-60.4	-44.7	34.1	163.2

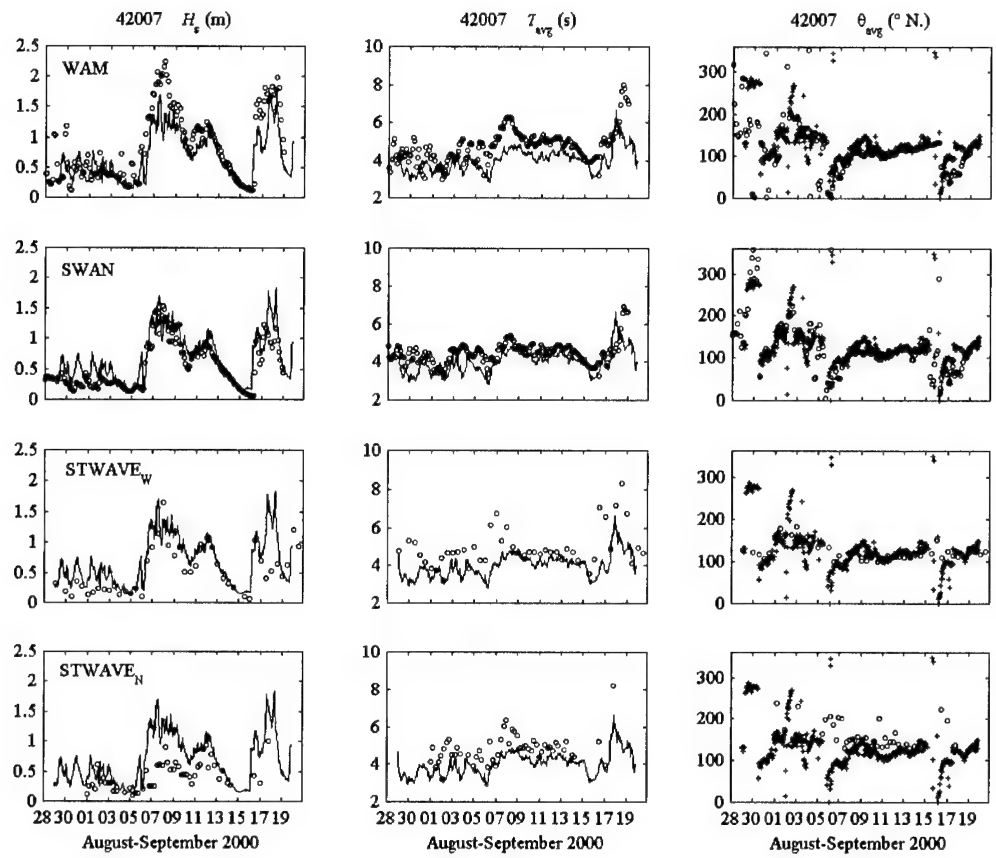

Fig. 16 —Times series of wave model estimates and NDBC measurements for wave parameters (solid lines) at the buoy locations indicated

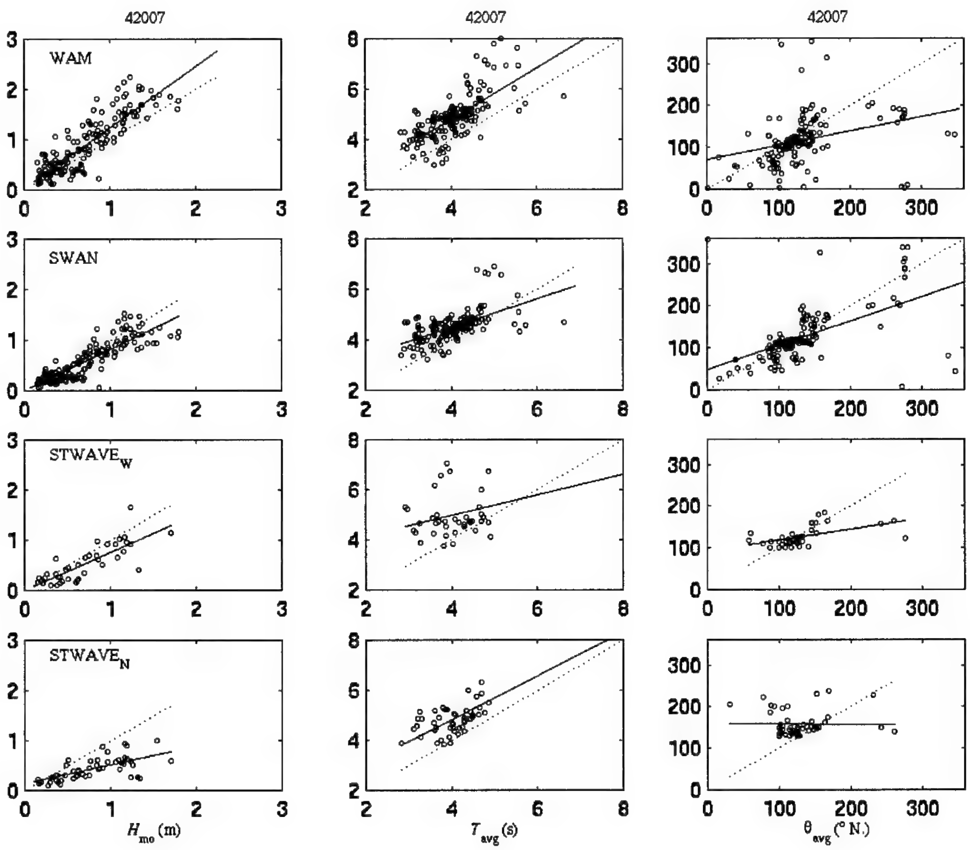

Fig. 17 — Scatter diagram of wave model estimates vs corresponding NDBC measurements for wave parameters at the buoy locations indicated. The solid line is the best-fitted linear regression line through the points. The dotted line has a slope of unity and a y-intercept of zero.

Table 10—Error Statistics of WAM, SWAN, and STWAVE Model Runs Minus NDBC Station 42007 for the Wave Parameters Wave Height, Average Wave Period, and Average Wave Direction Given in Figs. 16 and 17

42007 wave height (m)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	162	155	39	50
R	0.87	0.87	0.81	0.66
RMS	0.34	0.24	0.29	0.45
M	1.22	0.82	0.76	0.38
B	0.02	0.00	-0.00	0.14

42007 average wave period (s)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	162	155	39	58
R	0.70	0.58	0.25	0.65
RMS	1.02	0.72	1.37	0.99
M	0.98	0.71	1.17	0.61
B	0.71	0.21	-0.74	1.32

42007 average wave direction (deg N)	**WAM**	**SWAN**	**STWAVE$_W$**	**STWAVE$_N$**
N	162	155	39	58
R	0.69	0.71	0.52	0.32
RMS	24.5	21.3	15.1	25.1
M	0.67	0.77	0.23	0.25
B	29.6	31.4	94.5	118.0

8. DISCUSSION

SWAN offers many options in selecting the physics and model setup. Some of the important modeling parameters, such as whitecapping and bottom friction dissipation, are evaluated in the study.

8.1 Selection of SWAN Parameters

8.1.1 Wave Boundary Condition

There are two ways of feeding wave input into SWAN: BOUNDNEST and BOUNSPEC. In BOUNDNEST, a coarse grid model such as WAM produces a huge binary output for nesting. Because of its size, the restart file is not usually saved. In nesting, SWAN needs to be run on the same platform right after each WAM run. This arrangement requires SWAN runs to be put in the daily operational runstream, which is not practical for our model evaluation and validation. Our approach selects BOUNSPEC mode, in which WAM directional spectra are applied to boundaries. A small binary WAM directional spectra file for selected points is archived for each WAM run at 12-hour intervals. To assure the proper interpolation between input directional spectra along the boundaries, a spectrum file corresponding to zero wave heights is specified on the first land boundary on all side boundaries.

8.1.2 Frequency Range

In SWAN, the user can select the range and resolution for frequency. Because of the lack of swells with a very long period in the Gulf of Mexico, the lowest computational frequency is set at 0.06. The high frequency limit of SWAN is 1 Hz, whereas for most NDBC buoys it is at 0.35 Hz. The frequency cutoff for the buoy is related to hull response to waves; a shorter period wave height would require too much correction, making it inaccurate. In the Mississippi Bight, especially in the Sound, short waves are often present. Therefore, it is useful to examine the optimum upper limit of wave frequency. A comparison of wave height and mean (or average) period between the full range, i.e., cutoff at 1 Hz and cutoff at 0.35 Hz, is shown in Figs. 18 and 19. It is evident from Fig. 18 that the wave height increased by extending to 1 Hz is insignificant. However, the difference in mean wave period is significant. This is associated with the definition of mean period, which is weighted by frequency.

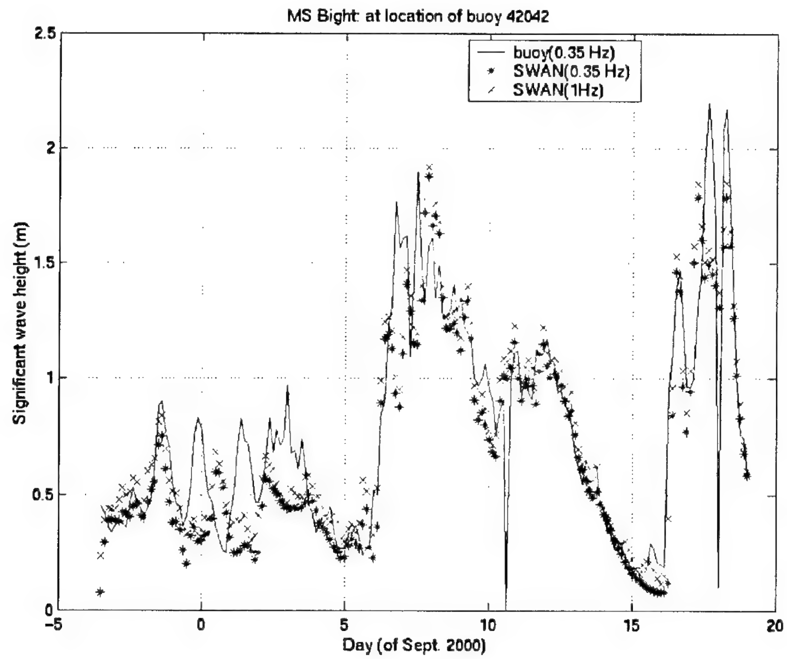

Fig. 18 — Comparison of wave height between frequency cutoff at 0.35 Hz and 1 Hz

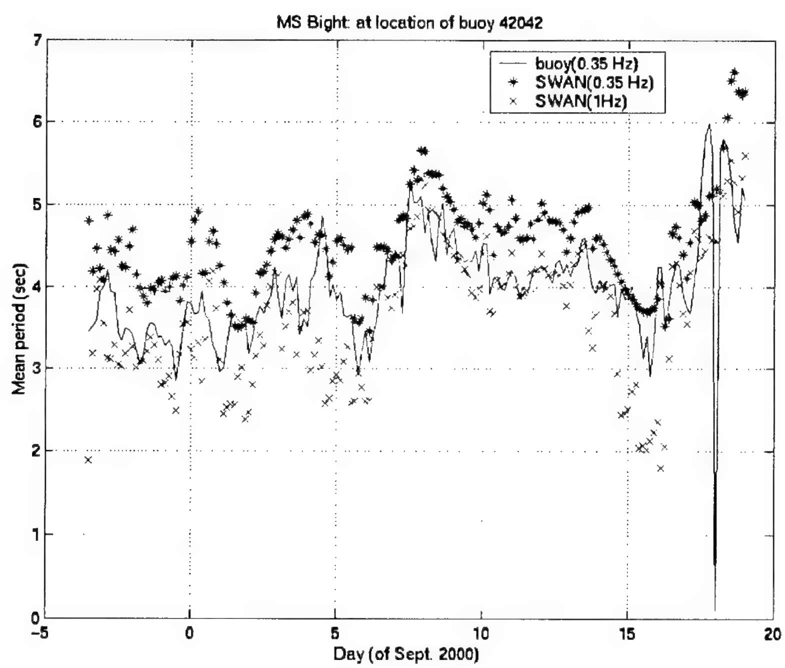

Fig. 19 — Comparison of mean wave period between frequency cutoff at 0.35 Hz and 1 Hz

8.1.3 The Whitecapping Dissipation

Whitecapping is primarily controlled by wave steepness. It not only affects the shape of the wave spectra, but also the growth rate of wave generation. The dissipation function is proportional to $(k/k_m)^n$ where k is the wave number, k_m is the mean wave number and n is a free or empirical parameter. In their previous study, Rogers et al. (2001) suggest that a value of 2 for n works better than the default value of 1. Both significant wave height and mean period between values of 1 and 2 are compared in Figs. 20 and 21. The results of n value of 2 do give better agreement with data. It should be noted that all SWAN results presented in the report are using a value of 2.

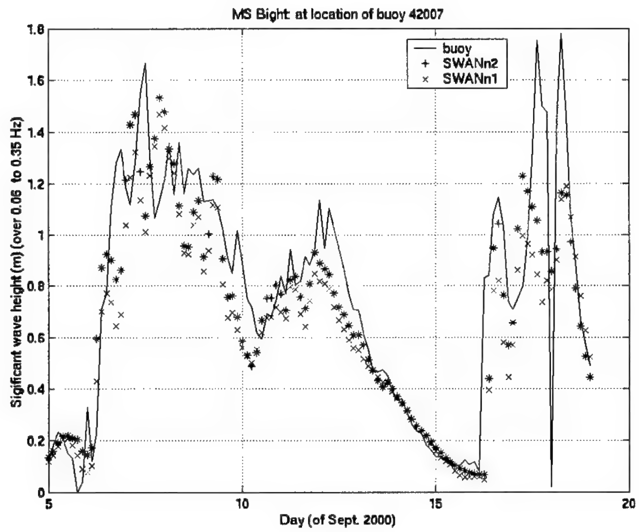

Fig. 20 — Wave height comparison between dissipation parameter (n) values of 1 and 2

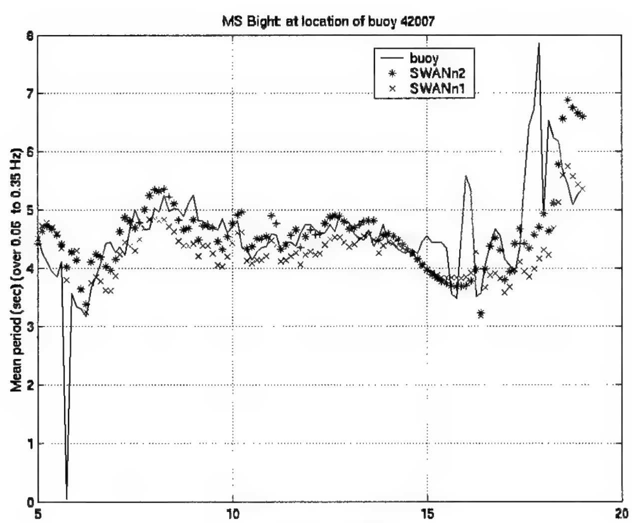

Fig. 21— Wave period comparison between dissipation parameter (n) values of 1 and 2

Figure 22 shows a sample comparison of spectral shape for Sept. 9. The case for *n* value of 2 produces less high-frequency energy and much better agreement with data at lower frequencies.

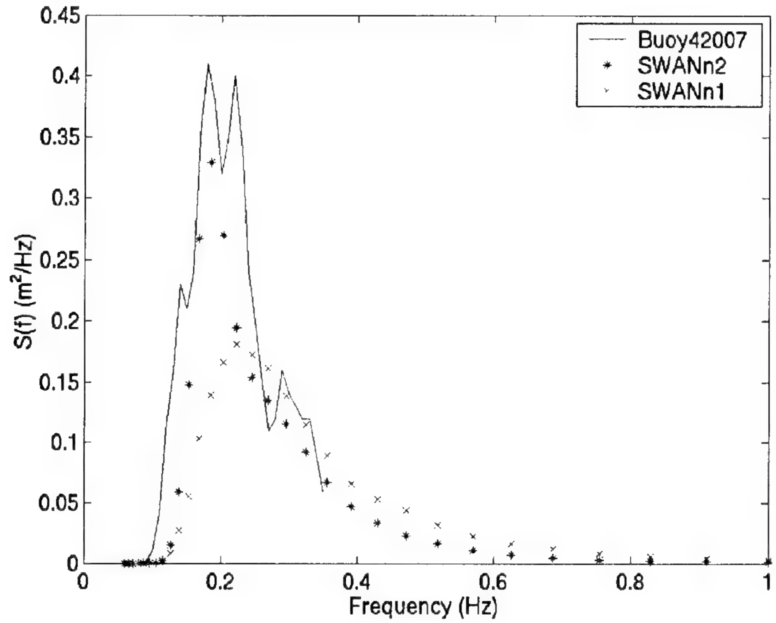

Fig. 22 —Spectral comparison between dissipation parameter (*n*) values of 1 and 2

8.1.4 Effect of Bottom Friction

SWAN incorporates several bottom friction options. The default is derived from Hasselmann et al. (1973). The default friction coefficient recommended for wind waves condition is 0.067, and is 0.038 for swell. However, SWAN offers no option for a combined wave and swell condition. The comparison between cases with and without bottom friction using a friction value of 0.067 is shown in Fig. 23. The substantial drop for the case with bottom friction indicates that waves are overdissipated. A calibration for bottom friction is beyond the scope of this study. It requires much longer record and choice of wave direction. At present, SWAN slightly underpredicts the waves, so including bottom friction is not a critical issue at least for offshore area outside the islands. Inside the sound, bottom friction should be included, but a careful selection of friction scheme and coefficient is required.

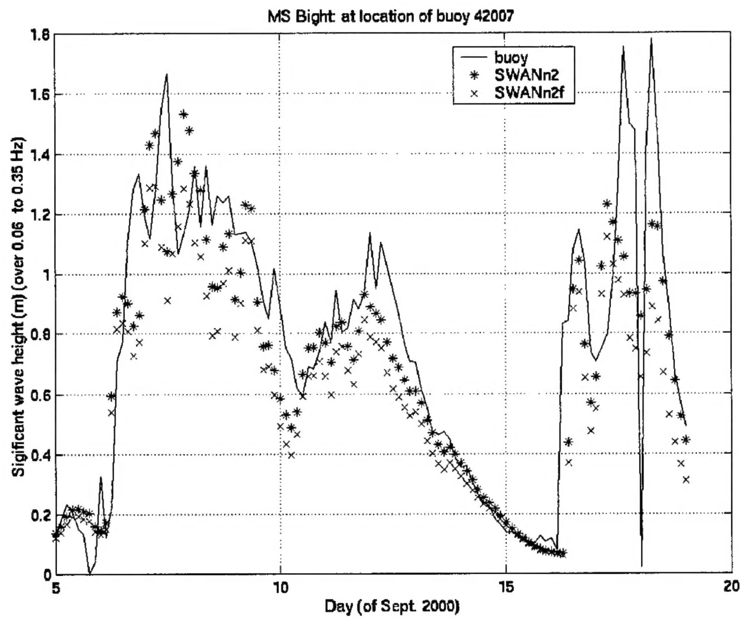

Fig. 23— Wave height comparison between cases with and without bottom friction

8.2 The Swell Event

The performance of SWAN under the swell event of Sept. 17 to Sept. 19 is not as good as it is under wind waves. Since its performance depends heavily on the accuracy of the WAM input, it is useful to examine the WAM performance in details. Tropical storm Gordon hit the Gulf of Mexico in mid September and eventually landed on the west coast of Florida. The storm generated rare long period swells. The arrival of swells can be examined by the peak wave period. Swells travel at group velocity, which is proportional to the period. The longer the period, the faster they travel and the sooner they arrive. The peak periods of all three buoys and WAM are presented in Fig. 24. It should be noted that during this period buoy 42040 experienced a satellite transmitter problem, thus much data are missing as represented by zero value and fall on the x axis. Since the swell is coming from southeast, it reaches buoy 42040 first. Swells from WAM are lagging behind, because it underpredicts the period. This fact of underprediction is also common for the global WAM model in other regions.

Figure 25 compares buoy spectral shapes for the early stage of a swell event. All three sets of buoy data show the arrival of the 11-second swell, whereas WAM completely misses it. Another spectral comparison at a later stage of the swell event is shown in Fig. 26. Buoy 42040 was not working, but the other two buoys were. SWAN agreement with buoys is reasonable. It is noted that the decrease of energy spectra from deep water (upper panel) to shallow water (lower panel) can be attributed to wave shoaling and refraction. The bathymetry contours in Fig. 1 clearly show that buoy 42007 is located in a trough, which caused the waves to be defocused.

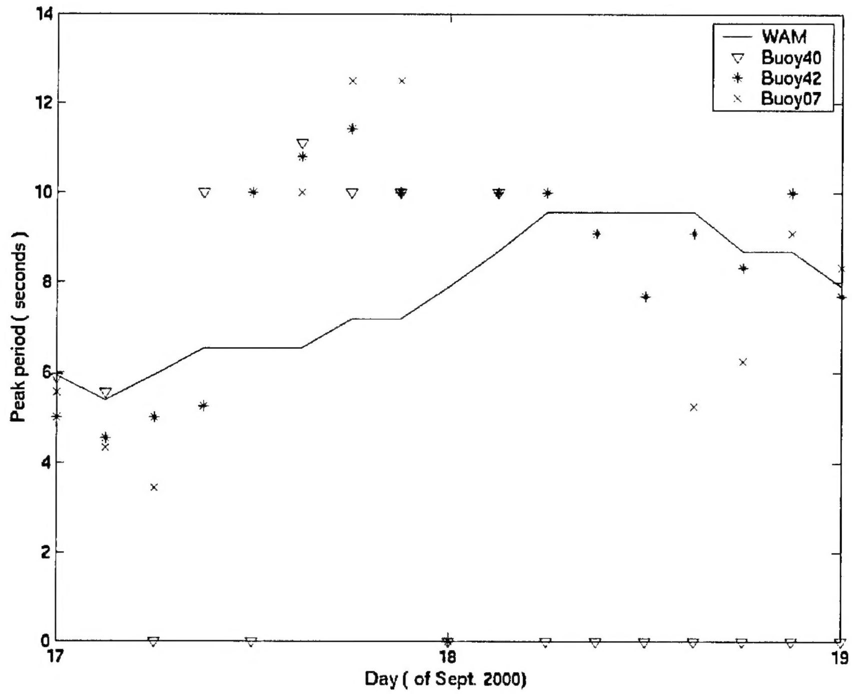

Fig. 24 — Comparison of peak period between WAM and buoys. WAM wave height is in the middle of the offshore boundary.

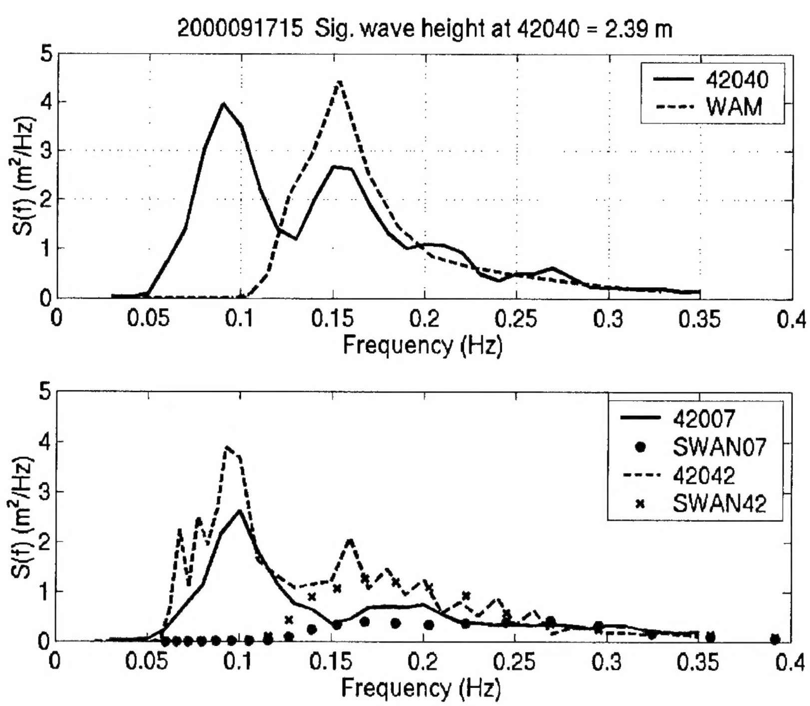

Fig. 25 — Comparison of spectra between WAM, SWAN, and buoys for hour 15, Sept. 17, 2000

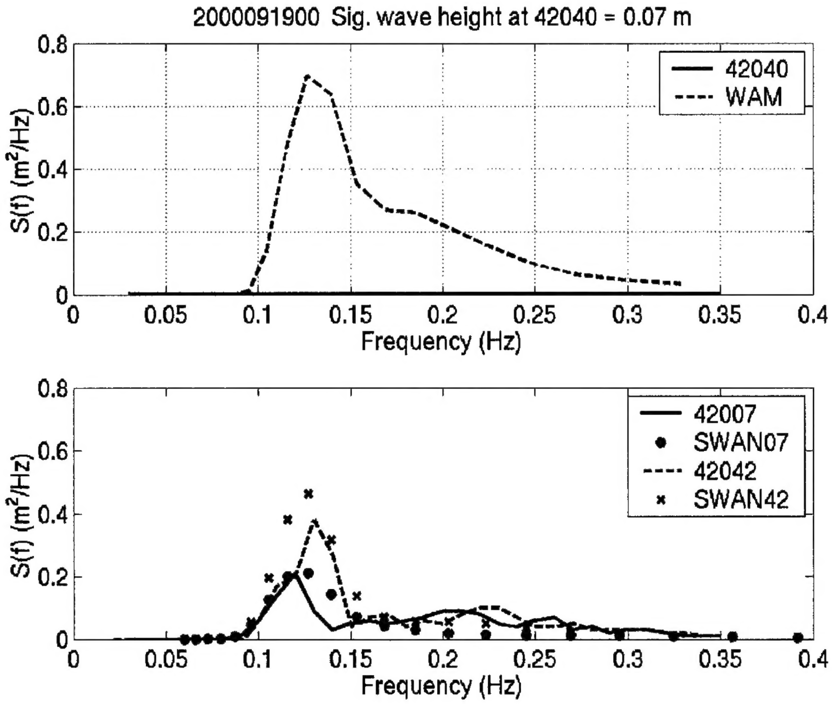

Fig. 26 — Comparison of spectra between WAM, SWAN, and buoys for hour 0, Sept. 19, 2000

9. SUMMARY AND CONCLUSION

The intensive field study period in Sept. 2000 produces a variety of wind and wave conditions. Comparison of the SeaBird SBE26 pressure gauge and the Neptune Trident wave buoy against corresponding wave measurements from an NDBC buoy indicate that both instruments provided reliable wave height and wave period measurements. The bias of wave angle measurements from the Triton buoy needs to be further examined. Due to the unpredictable nature of weather events, it is recommended that longer deployment duration of at least up to one month should be used in the future.

COAMPS, WAM, STWAVE, and SWAN are evaluated and validated using three NDBC buoys. Other wave gauge data from pressure gauge and a portable wave buoy are not used due to their short duration of deployment. COAMPS wind agrees well with all three buoy data sets. It has an average RMS error of 2 m/s. Except for the rare swell event, regional WAM under COAMPS wind produces accurate input boundary conditions for driving the shallow water models. The WAM results compare well with buoy 42042 (depth 35 m). This information is used in the final domain selection of the operational SWAN model. The operational wave-forecasting model (http://128.160.23.41/Products/modeling/swan) in Mississippi Sound for the NGLI web page starts at a water depth of 50 m, resulting in a substantial reduction in computation time.

SWAN produces an average RMS error of 0.3 m in significant wave height. SWAN's performance depends heavily on the accuracy of the WAM input. Consequently, its performance is better under the wind wave condition than the swell condition. The analysis of model errors of SWAN and STWAVE in this study clearly demonstrates that the SWAN model is superior to the STWAVE model. STWAVE's poorer performance is mainly due to its limitation in specifying the wind and wave boundary condition.

10. ACKNOWLEDGMENTS

Mr. James Dykes of NAVOVEANO made the WAM runs used for SWAN and STWAVE boundary conditions and implemented the operational scripts in the NAVOVEANO daily runstream. Mr. Carl Szczechowski of NAVOCEANO provided the depth survey data used to produce the depth fields used with the SWAN and STWAVE runs. Model runs were made using computer resources provided by the Department of Defense Major Shared Resources Center (DOD MSRC) at the Naval Oceanographic Office. Mr. Erick Rogers/NRL provides assistance in SWAN setup and graphics. Mr. Kelly Miles from Sverdrup Technology, Inc. helps in developing the operational scripts. Dr. Chung Chu Teng/NDBC provided experimental directional buoy 42042. Mr. Rex Hervey provided all requested NDBC data.

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